Environmental Science

HP COMPUTER CURRICULUM

Air Pollution

STUDENT LAB BOOK

HEWLETT hp PACKARD

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Hewlett-Packard
Computer Curriculum Series

environmental science
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air pollution

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Hewlett-Packard Company
11000 Wolfe Road
Cupertino, California 95014

HP 5951-4469

January 1973

The Hewlett-Packard Computer Curriculum Series represents the published results of a Curriculum Development project sponsored by the Data Systems Division of Hewlett-Packard Company. This project is under the directorship of Jean H. Danver.

This material is designed to be used with any Hewlett-Packard system with the BASIC programming language such as the 9830A Educational BASIC, and the 2000 and 3000 series systems.

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Printed in the U.S.A.

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INTRODUCTION

This Environmental Science Lab Book was developed to provide you the opportunity to use a computer as a problem solving tool. You will write computer programs which will enable you to investigate a serious contemporary problem—air pollution. If you become more concerned with this growing threat to our environment and especially if you can produce viable ideas for solving the problem, this Lab Book will have achieved its aim.

To use the Lab Book for Air Pollution, you will not need to be expert in mathematics, so if your background is shaky, relax! Only the beginning principles of algebra will be used. You should, however, know how to write simple programs in the BASIC programming language. If you do not, you will want to study this before you attempt the material. Consult the BASIC manual for the computer you use. You also need to have access to a computer for at least one hour per week in order to gain maximum benefit from the material. If more time is available, you may decide to experiment further on your own, either to improve your programs or to investigate other areas that interest you.

As you will discover, there is no one "right" way to use a computer as a problem solving tool. There are many different ways to solve a given problem by programming. Experiment and learn as you go. You'll find you are learning something new each time you use the computer, both about your subject matter and about using the computer to solve problems.

This book was designed to help you by providing several different kinds of material. First, there are very simple exercises with the necessary explanatory material. Next, there are exercises which require that you make generalizations from the results of your early investigations. Generally, these exercises are sequences so you can apply what you have learned in previous problems when solving the next one. Often you can take your preceding program and simply add to it to create a program that will provide answers to the more general or more advanced problem. Last, some advanced exercises are included which may be "open ended," i.e., they can be expanded into as detailed an investigation as you choose.

When you begin using the Lab Book, you should develop the habit of planning a solution in the form of a flow chart before writing the program. This is good programming practice. Drawing the flow chart provides a check of your logic, and the finished flow chart can then be used as a guide in writing each step of your program.

PROBLEM MODELLING

The second half of the twentieth century has seen an almost cancerous growth of serious ecological problems in the United States. On all sides, crises seem to be multiplying at an alarming rate. Fifty years ago, clean water was the rule. Now it is difficult to find a river safe for swimming, let alone drinking. Two decades ago, "smog jokes" were reserved solely for residents in the Los Angeles area. Today, air pollution is a fact of life across the nation. Freeway systems created to relieve traffic congestion have wound up producing even more congestion. Population growth and movement patterns have created critical sociological stresses in our large cities.

Increasingly, it seems that we are victims of circumstance, and we are certainly unable to define the scope and magnitude of the problems which are confronting us. The remedy most often applied is uninformed talk, instead of much-needed action. Meanwhile, the problems continue to grow. One very significant deterrent to action is the fact that the problems are so complex that cause and effect are difficult to define. An attempted solution to one problem sometimes creates another equally hazardous situation. The problems caused by the use of pesticides are an excellent example.

One of the best ways to approach any complex problem is by using a model. If we can construct a mathematical model which accurately describes the phenomena under investigation, we can use the model to study the phenomena and to predict outcomes. Potentially dangerous situations can be detected and possible solutions tested by "twisting the model's tail." This approach has been used in design technology for years. For example, the jumbo jets made countless flights on paper in terms of a mathematical model before the real aircraft actually flew. Problems discovered in flight are far more expensive, both financially and in terms of human life than those discovered with a mathematical model. However, when one attempts to create a mathematical model to investigate any meaningful problem, the fundamental difficulty becomes clear. The problems of interest are usually incredibly involved and simply can't be solved by usual paper and pencil mathematics. All this changes when a computer is available. Its computational speed permits successful modelling of the most complex problems.

In this unit, we will investigate one of the most perplexing problems facing our society: air pollution. We will use the computer to probe the dimensions of this problem, try to get insight into possible alternatives, and hopefully come up with a viable solution. In this unit, there are *no approved solutions* to the exercises. If fifty students work the exercises, there may well be fifty different sets of results. Use the following to judge your results: have you accomplished what was assigned by the problem, how well do your results compare to the "live" situation, and how much insight into the problem have you acquired?

Finally, you will discover that using the computer to investigate a relevant problem such as air pollution is a new and challenging experience. While we will be concerned solely with air pollution, the methods introduced can be applied with equal success to almost any environmental problem.

COMPONENTS OF AIR POLLUTION

Air pollution is a very complex problem involving many different kinds of pollutants which produce a wide variety of effects. To simplify matters, pollutants are usually divided into two general classes: particulate matter (either solid or liquid), and gases.

Particulate matter is generated in many industrial processes. Plumes of smoke emanating from factories are visible evidence of particulate matter. Factory pollution, fortunately, is fairly easy to control at the source. Agricultural and construction activities, on the other hand, are other sources of particulate pollutants which are more difficult to control. Open burning, forest fires, etc., can throw large quantities of particulate matter into the air, mostly carbon and various other materials released during incomplete combustion. Some liquid droplets contribute to air pollution. One serious example (sulfuric acid) will be discussed later in the unit. Many special sources of particulate matter are also present in our society. An example which is currently receiving a great deal of attention is our freeways, where tons of lead are released from automobiles burning leaded gas.

For convenience, the pollutant gases are divided into four categories: *sulfur oxides*, *organics*, *oxides of nitrogen*, and *carbon monoxide*. Combustion processes also produce large quantities of carbon dioxide but we will ignore it since it is a natural component of all air. (Actually, from the global, long-range point of view, the gradual increase in carbon dioxide concentration in the atmosphere may be the most disastrous effect of air pollution.)

Coal and some types of cheap oil contain small quantities of sulfur. When these fuels are burned, *sulfur oxides* (sulfur dioxide and sulfur trioxide) are generated. Sulfur trioxide can combine with water vapor in the air to form *sulfuric acid*, which is harmful to almost everything. Oxides of sulfur generally give a dirty yellow tinge to the air. High sulfur dioxide concentrations have led to major air pollution disasters (Meuse Valley, Belgium–1930; Donora, Pennsylvania–1948; London–1952 and 1962).

Organic gases are released when many of the sophisticated new materials (plastics, synthetics, etc.) are burned. Organic gases also enter the atmosphere when paints, gasoline, and similar substances evaporate. These organic gases are very hazardous because they can combine with oxides of nitrogen in the presence of sunlight to form *photochemical smog*, one of the most severe problems associated with air pollution.

The atmosphere is about 80% nitrogen. Any time combustion takes place at sufficiently high temperatures, some of the nitrogen in the air is "burned" or *oxidized* to form nitric oxide and nitrogen dioxide. These two oxides of nitrogen comprise one of the major gaseous pollutants. Nitrogen dioxide produces a "whiskey brown" haze in the atmosphere. In addition, nitrogen dioxide, organic gases, and sunshine can combine to produce photochemical smog.

The last type of pollutant gas is carbon monoxide. This gas is a constant companion of combustion. Something like 90% of all the carbon monoxide in the atmosphere comes from the internal combustion engine, i.e., the automobile. The gas is odorless, invisible, and can be very *dangerous*. If exposure is high enough, dizziness, uncon-

sciousness, and even death can result. Carbon monoxide is a puzzling pollutant: it is being produced by automobiles at a fairly steady rate, but the average concentration remains quite low. At the present time, no one knows just what is happening to this gas!

The purpose of this rather detailed description of air pollution is not to make chemists of you, much as it might seem like it. We will be building various computer models around air pollution and will want to keep as close to fact as possible. Consequently, we need to be familiar with the various components of air pollution. The terms *particulates, organics, nitrogen oxides, sulfur oxides,* and *carbon monoxide* will be used continually throughout this unit. You should therefore make a point of adding these words to your vocabulary now. Occasionally we will use symbols to refer to these new terms. Org. will stand for organics, NO_X for nitrogen oxides, SO_X for sulfur oxides, CO for carbon monoxide, and part. for particulates.

THE AUTOMOBILE AND AIR POLLUTION

The most logical place to begin our study of air pollution is with the automobile. Table 1 presents some very interesting statistics concerning the relationship between cars and air pollution. First, the overall quantity of pollutants (141 million tons per year) is absolutely depressing! Second, the automobile plays a discouragingly large part in the overall pollution. Certainly in the production of carbon monoxide (93% of the total) and organics (66% of the total), the automobile is the villain! Last, it is clear that the automobile has little to do with pollution from sulfur oxides and particulates.

Table 1 – Total US Air Pollution (1970)

Pollutant	Millions of Tons Per Year			% Caused by Auto
	Auto	Other	Total	
Carbon Monoxide	66	5	71	93
Organics	12	7	19	63
Oxides of Nitrogen	6	7	13	46
Sulfur Oxides	1	25	26	4
Particulates	1	11	12	8
Total Pollutants	86	55	141	61

Before we can start building our automobile air pollution models, we need to know the rates at which automobiles produce the various pollutants. Of course, this is continually changing as automobile pollution controls become more severe. We will use 1970 estimates (hopefully, by 1980 or 1990 the values will be much lower). Also, we will assume a standard velocity of 40 miles per hour. Do you feel this is a reasonable choice? The rates of pollutant production are given in Table 2.

Table 2 – Average 1970 Pollutant Production Rates per Automobile Traveling at 40 MPH

Pollutants	Rate of Production		
Gases	liters/mile	cubic feet/mile	grams/hour
Org.	4.5*	6.4	483
NO_x	3.4**	4.8	231
SO_x	0.1***	0.14	11.4
CO	54.1	76.6	2710
	(grams/mile)		(grams/hour)
Particulates	0.5		20

**Assumes an average molecular weight of 60. Gas volumes computed at standard temperature and pressure.*
***Assumes equal parts nitric oxide and nitrogen dioxide are formed. Average molecular weight of oxides of nitrogen assumed to be 38.*
****Assumes 4 parts sulfur dioxide to 1 part sulfur trioxide are formed. Average molecular weight of sulfur oxides assumed to be 67.*

Let's take an average residential district, composed of a mixture of apartments and single family dwellings, as the subject of our first air pollution model. Suppose that the residential district is square with one mile sides and that we are concerned with the air over the district up to an elevation of 500 feet. Moreover, we will assume that no air passes in or out of our residential district and that any pollutants created are uniformly distributed through the air up to our "ceiling" of 500 feet.

These assumptions are typical of the ones we will be making continually. Certainly they are crude, and you may be in complete disagreement. However, experience shows that it is a valid approach to start with a very crude model and then refine it.

EXERCISE 1 – Estimating Number of Cars

> *How many automobiles would you expect to find in our residential area? How many automobiles would you expect to find running at some arbitrary time? You will have to make some assumptions to reach your answer. Be sure and state these assumptions explicitly. Compare your assumptions to those of other students. Do your assumptions stand up well under close examination?*

Now that you have estimated the number of cars, we will structure our first model. Let P stand for the number of cubic feet of pollutants at any time, R for the number of cubic feet of pollutants produced per hour by each car, and N for the number of cars operating at any given time. The simplest model we could construct would be

$$P_{new} = P_{old} + (R)(N)\,. \tag{1}$$

P_{new} is the amount of pollutants at the end of any hour. P_{old} is the amount at the end of the previous hour.

Initially, let's concentrate solely on carbon monoxide pollution. This gas is fairly stable and quite persistent. We will need some concentrations and their effects to use in the exercises. A carbon monoxide concentration of 1000 parts carbon monoxide to one million parts air (abbreviated 1000 ppm) is sufficient to produce unconsciousness in 1 hour and death in 4 hours. The maximum allowable concentration for industrial workers for an eight-hour working day is 50 ppm. Concentrations of from 25 to 50 ppm will be experienced inside an automobile moving in a heavy stream of traffic in a multilane highway or freeway.

EXERCISE 2 – A Simple Model

> *Write a BASIC program to compute and print out the number of cubic feet of carbon monoxide in our residential area every hour for a 24-hour period. Assume that at the beginning there is no carbon monoxide in the air. Use the number of cars running which you estimated in Exercise 1. The carbon monoxide production rate per car can be obtained from Table 2.*

EXERCISE 3 – Computing Concentrations

> *Modify the program in Exercise 2 to print out the carbon monoxide concentration in ppm (parts per million) at the end of every hour.*

EXERCISE 4 – Lethal Concentrations

Using elementary algebra, compute how long it will take to reach the lethal concentration of 1000 ppm in the residential district. Make the same assumptions as for Exercise 2. Taking the fundamental assumptions of our model into account, do you feel there is a carbon monoxide hazard associated with life in a normal residential area?

EXERCISE 5 – A Garage Problem

Use algebra to compute how long it will take for a single automobile, in a closed garage with the engine running at a speed equivalent to 40 mph, to produce a carbon monoxide concentration of 1000 ppm. State clearly any assumptions you make. Is there a hazard here?

EXERCISE 6 – Intersecting Freeways

Suppose that two major freeways cut across our residential district and intersect at the center. Use the model given by (1) and compute the carbon monoxide concentration in ppm. State any assumptions which you must make. Do you feel there is a carbon monoxide hazard in this situation?

EXERCISE 7 – A Tunnel Problem

It is not uncommon to find highway tunnels one mile long carrying two lanes of traffic in each tube. Suppose the ventilation fans went out just as you entered the tunnel. Is there a carbon monoxide hazard? State any assumptions you make.

By now you surely have detected serious flaws in our model. We have been handling only carbon monoxide but, according to Table 2, there are other pollutants present. We have assumed that no air moves in or out of our residential district, but usually there is at least *some* wind, and wind certainly carries away pollutants. Also, we have assumed that once pollutants are created, they are with us forever. However, the pollutants do break down, or are gradually eliminated from the air by mechanisms other than wind.

The next task is to "patch up" the model given by (1) to make it more realistic. First, we will redefine P. Let P stand for the total number of grams of pollutants of *any* kind in the system. To account for wind effects, assume that if W is the wind velocity in miles per hour during any hour-long period, that $(W/50)P$ is the amount of pollutants that is removed during that hour. We will limit wind velocities to the range 0 to 50 mph. As you can see, a velocity of 0 means that no pollutants are removed during the hour, and a velocity of 50 mph implies that all the smog is blown out during the hour. Do you think this is reasonable? If not, you might want to make assumptions of your own. Finally, let's assume that $R_2 P$ of the pollutants disappear during an hour from dissipation mechanisms.

Now we can write down our new model:

$$P_{new} = P_{old} + R_1 N - \frac{W}{50} P_{old} - R_2 P_{old} . \qquad (2)$$

P (either "old" or "new") stands for the total number of grams of pollutants in the system. R_1 is the total amount of pollutants (in grams) produced per hour per car. N is the number of cars operating (remember that we are assuming 40 mph). W is the wind velocity in miles per hour. R_2 is the decimal part of the pollutants that is dissipated each hour from causes other than wind or weather.

If we let C stand for the concentration of pollutants in milligrams (thousandths of a gram) per cubic foot, then C must be given by

$$C = \frac{1000P_{new}}{V} \tag{3}$$

where V is the volume of the system in cubic feet. The combination of Equations (2) and (3) gives us our new model and allows us to compute the pollutant concentration in milligrams per cubic foot.

EXERCISE 8 – A New Model

Suppose we examine an intersection of two major freeways. Let's assume that each freeway has four lanes of traffic in each direction. Consider as our "system" a block of air, 2000 feet on a side and 500 feet high, centered on the freeway intersection. Assume that the traffic flow saturates the freeways and remains constant. Assume a wind velocity of 5 mph, and $R_2 = .01$. Write a BASIC program using Equations (2) and (3) to print out C every hour, assuming that the initial value of P is zero. Run the program until C does not change further. Draw a rough graph of your results.

EXERCISE 9 – Equilibrium Concentration

If C does not change, the system has reached equilibrium. *When this is true, $P_{new} = P_{old} = P_{eq}$. Use some simple algebra in Equations (2) and (3) to predict mathematically the equilibrium value of C. Check your answer against the results of Exercise 8.*

EXERCISE 10 – Turning the Wind Off

Use the program from Exercise 8 to investigate the effects of turning the wind on and off. Your program printouts should show two equilibrium values of concentration, with and without wind! Can you find both of these algebraically?

EXERCISE 11 – Closing Down Freeways

Use the program from Exercise 8 and any wind velocity you desire. What happens to C if the freeways are shut down at some particular instant? Sketch a rough graph of the program printout.

We still have serious flaws in our automobile air pollution model. We have been assuming *constant* values of N, W, and R_2. Clearly, this isn't realistic. It is common experience that there are morning and afternoon traffic rush hours, and that very little traffic is on the street in the middle of the night. Also, the wind rarely blows with constant velocity. Finally, the dissipation rate R_2 is certainly not constant.

As we discussed previously, photochemical smog is the result of organics, oxides of nitrogen and sunlight. It stands to reason that R_2 should be smaller during hours of sunlight than during hours of darkness.

It will be fairly easy to take these ideas into account and make our model *much* more realistic. The key is to assume *maximum* values of N, W, and R_2, then take hourly decimal parts of the maximum values. Thus we can set up one list of 24 factors to be applied to N, another list for W, and so on. Each of these lists constitutes a time profile of each factor. Now, the model is

$$P_{new} = P_{old} + R_1 X_i N - Y_i W P_{old}/50 - Z_i R_2 P_{old} . \qquad (4)$$

X_i is the traffic profile factor (applied to N), Y_i is the wind profile factor, and Z_i is the dissipation profile factor. The subscript i is the hour number (1 to 24). So we can compare results, let's agree that hour number 1 in any day is from midnight to 1 a.m.

EXERCISE 12 – A Time Dependent Model

Write a BASIC program to evaluate the model given by (4) applied to the freeway example in Exercise 8. Assume reasonable sets of values for X, Y, and Z. Print out C every hour. Sketch your results in a simple graph.

EXERCISE 13 – Political Questions

Use the model developed in Exercise 12 on a system whose characteristics are specified by you. Run the program to get a feel for the pollutant concentrations that come out of the model. Now, suppose that the edict has come down to cut down on pollution. Use your model and program to investigate the question. Make realistic *suggestions as to how the pollution concentration from automobiles might be cut down.*

INDUSTRY AND AIR POLLUTION

So far, the automobile has been the sole object of our investigation. We've emphasized the automobile since it is the source of about 60% of all air pollution in the United States. Now let's turn our attention to the other 40%.

The industrial air pollutants are the same ones we have already discussed; particulates, sulfur oxides, organics, oxides of nitrogen, and carbon monoxide. Table 3 shows typical air pollutant production rates associated with various types of industrial activity. These figures will vary from firm to firm, and will depend on the plant size and the pollution controls in use. However, they are typical and can be used to get insight into the problem.

Table 3 – Typical Industrial Pollutant Production Rates

Industrial Activity	Contaminants (tons per day)					
	Part.	SO_x	Org.	NO_x	CO	Total
Smelting	0.4	78	0.1	0.2	15	93.7
Oil Refining	1.6	17.9	9.9	10.7	13.3	53.4
Electricity Generation	0.9	6.4	0.1	2.3	–	9.7
Sugar Refining	0.3	3.5	–	2.1	0.3	6.2
Cement Manufacture	0.5	0.1	0.1	5.0	0.6	6.3
Jet Aircraft Maintenance	0.4	0.5	0.2	0.1	1.1	2.3
Railroad Shop	0.4	0.1	0.1	0.2	0.1	0.9
Meat Packing	–	–	0.1	0.1	–	0.2
Electronic Manufacture	–	–	–	0.1	–	0.1
Sand & Gravel Production	0.1	–	–	–	–	0.1

The first thing that is apparent in the data in Table 3 is that while sulfur oxide production was insignificant when considering the automobile as a source of pollution, it is the major concern in evaluating industrial activities as pollution sources. Smelting seems to be particularly bad in this respect. A classic example of environmental damage from smelting has taken place in the area between Phoenix and Tucson in Arizona. This desert area has long been famous for its unbelievably clear, dry air. Several major astronomical observatories were located in this region because of the clear air. Now, however, serious sulfur oxide air pollution problems are growing becuase of copper smelting activities in the area. Instead of clear, sunny skies, the area often has the characteristic dirty yellow air associated with sulfur oxide pollution. Remember that sulfur trioxide plus water vapor (from irrigated fields if nowhere else) yields sulfuric acid and lots of trouble. The people in Arizona are currently caught between the desire for a dynamic copper industry and clean desert air.

Oil refineries are also heavy air polluters. Besides emitting large quantities of sulfur oxide (have you seen trails of yellow smoke coming from standpipes in oil refineries?), they also give off considerable organics and oxides of nitrogen. Combine oil refineries with lots of automobiles, plenty of warm sunshine, and not too much wind, and you have a ghastly photochemical smog problem! For a very good example

of this combination, visit the concentration of oil refineries along the San Diego Freeway in the Signal Hill area between Long Beach and Los Angeles. This area has all the necessary ingredients for photochemical smog, the number one air pollution problem in California!

We can see from Table 3 that there are relatively clean industries, for example, electronic manufacture with only 200 pounds of contaminants per day. This is a far cry from the 100 tons of pollutants a day from a smelter.

These production rates demonstrate why all types of industry are not equally welcome in a community. They also show why all that is needed to have an air pollution problem *anywhere* is a sufficiently high concentration of polluting industries. It is true that some areas are favored with natural ventilating winds a large percentage of the time. However, even these areas (such as the San Francisco Bay area) can have pollution problems when the density of people, cars, and industry gets high enough.

We can use some of the ideas already developed for the automobile to investigate the effects of industrial air pollution on a city. To do this, let's use an idealized model of a city three miles on a side, composed of nine zones. Suppose that each zone is one square mile in area, and one mile on each side. Further suppose that the city is classified by function as follows:

4 zones – Residential (R)
2 zones – Light Industrial (LI)
1 zone – Heavy Industrial (HI)
1 zone – Parks and Recreation (P)
1 zone – Commercial (C)

One possible way the city could be laid out is shown in Figure 1.

LI	R	C
P	HI	R
R	R	LI

Figure 1 – Block Diagram of City

Before starting on our computer model, a few exercises involving just plain thinking are in order.

EXERCISE 14 – A Zoning Request

Suppose that you are a member of a zoning board, and the plan given in Figure 1 comes before the board. All the information you have is that given on the diagram. Would you vote for approval of the zoning request? Explain your answer.

EXERCISE 15 – Zoning Modification

Given the situation in Exercise 14, suppose you cannot get any additional information but you can shift the zoning blocks around any way you choose as long as the result is a 3-mile-square city. How would you set up the city? State clearly the criteria you use in reaching your answer.

EXERCISE 16 – More Information

The zoning board receives the plan in Exercise 14 and properly refuses to make a decision because of lack of information. What additional information would you request to enable you to make the best decision?

Up to this point, we have been using very subjective methods of judging the zoning of the city. We may *feel* we are right, but judging by feeling is not very reliable. What we need is a computer model to permit us to make as rational a decision as possible. We run a constant danger that the model might be faulty and describe a situation that doesn't exist. However, a good model optimizes our chances of making a correct decision.

The model we will develop is somewhat different than the ones for the automobile. We will call it a diffusion model for reasons which will soon be clear. The following assumptions are made:

(a) The city is a closed system, i.e., no pollutants cross the edges of the city.

(b) Pollutants are produced at a constant rate in each zone, the rate determined by the activity in that zone.

(c) Pollutants diffuse from one zone into another. Let us arbitrarily decide that in a one-hour period, 10% of the pollutants in any zone at the beginning of that hour diffuse across any common boundary with another zone.

Our model takes on the following form:

$$P_{new} = P_{old} + R - D_{out} + D_{in} \tag{5}$$

where R is the hourly production rate, D_{out} is the diffusion of pollutants out of the zone, and D_{in} is the diffusion of pollutants into the zone.

This type model lends itself to matrix methods on the computer. You might ask your instructor for help if you are not already familiar with matrix methods.

EXERCISE 17 – A Zoning Model

Assume any reasonable *pollutant production rate for each type zone. You can figure that a car produces about 7.6 pounds of pollutants in one hour of operation, and you can find industrial factors in Table 3. You will have to decide how many and what type of polluting activities are in each zone, and then reach a total pollutant production rate for that zone. Write a BASIC program to compute the amount of pollutants (tons) in each of the zones in Figure 1 on an hourly basis for 24 hours, using the model given by Equation 5.*

EXERCISE 18 – Restructure of The City

Use the same zonal production rates as in Exercise 17, but rearrange the zones to some optimum configuration as demonstrated by the computer model. What criteria did you use to determine what the "best" configuration is?

EXERCISE 19 – Model Your Own Town

Using the methods utilized above, make a rough block model of your own town. You may need a smaller zone size than one square mile. Can you build in a weather factor? What about pollutant breakdown? Of all the exercises thus far, this one is the most open-ended, and susceptible to individual ideas and initiative.

PEOPLE AND AIR POLLUTION

In the previous sections we have been examining air pollution in a somewhat abstract sense, citing pollution components and quoting production rates as if the pollution problem had no connection with people. Of course, the exact opposite is true. Air pollution occurs *because of people.* No people: no air pollution. The more people: the greater the problem.

An example will clear up this point. In 1970, the nine counties comprising the San Francisco Bay Area had total daily pollutant production rates (tons per day) as follows: particulates–207, organics–1720, oxides of nitrogen–629, sulfur oxides –284, and carbon monoxide–5785. The population in these nine counties during 1970 was 4,508,300. Each person in the Bay Area carries around his own little private cloud of pollutants (remember Joe Btffplk of Little Abner fame?). We can compute the approximate daily quantities of pollution per person (see Table 4).

Table 4 – Per Capita Daily Pollutant Production Rates
San Francisco Bay Area (1970)

Pollutant	Daily Rate	
	pounds/day	cubic feet/day*
Part.	0.09	–
Org.	0.76	4.5
NO_x	0.28	2.6
SO_x	0.13	0.7
CO	2.56	32.6

**Same assumptions as in Table 2.*

We will assume that the rates per person in Table 4 are typical of any U.S. citizen. It is true that the San Francisco Bay Area isn't exactly typical geography, but it is a fair average between remote or uninhabited areas and the highly concentrated industrial areas in the "megalopolis" stretching from Boston to Washington, D.C. In any event, we will consider the rates as typical.

The natural mechanisms which break down or remove pollutants from the atmosphere function on a geographical and not on a per capita basis. Consequently, when the population in a given geographical region generates pollutants at a rate greater than the "natural defenses" can handle, air pollution and associated problems are the result.

EXERCISE 20 – People and Pollution

Suppose we consider a city five miles square. We will examine the pollution problems from various populations, starting with 1000 people living in this city, then 2000, 3000, and so on. Write a BASIC program to compute the concentration of Org., SO_x, NO_x, and CO (in parts per million), as well as particulates (milligrams per cubic foot) in the air space over the city for the

population as it increases in increments of 1000. For each population, consider only a single 24-hour period and assume there are no dissipation mechanisms at work. Use the daily production rates in Table 4. State clearly any assumptions you make.

EXERCISE 21 – Dissipation Mechanisms

Add dissipation mechanisms to the program in Exercise 20. Build these in any way you feel is reasonable. Some factors which affect the dissipation process are sunny versus cloudy days, rain, wind, inversion layers, geography, and chemical breakdown of pollutants. Which pollutants tend to be eliminated in your model? Again, be specific about any assumptions you make.

EXERCISE 22 – A Segmented Model

Break the city of Exercise 20 into 25 segments, 1 mile on each side. Modify the per capita production rates in Table 4 to hourly production rates. Make a coupled model, i.e., a model in which pollutants generated in one zone can either wind up in another zone or can leave the system. The coupling can be from wind, dispersion, or any mechanism you desire. Write a BASIC program which will help you study the implications of your model.

EXERCISE 23 – A Real City

Look at a map of the greater Los Angeles area. Assume that the population is uniformly distributed over the Los Angeles basin. Prevailing winds are generally low and are inland from the ocean. Use the knowledge gained in Exercise 22 to predict where the air pollution problem will be the most severe. Explain why.

THE FUTURE

The ultimate problem which must be solved concerns the relationship between people and air pollution. The pollutants are with us because we have a large population and a high energy consumption per person. People demand more and more products which require a higher energy input into industrial machinery, which in turn leads to higher industrial pollution. Population growth and movement produces human densities in certain regions such that natural dissipation processes are overcome.

The answers to the nagging question of air pollution are not simple, will not provide immediate relief, and will cause both political and economic reverberations throughout our society. Painful as this may be, ignoring the problem will be catastrophic in the long run. All over the United States, organizations and agencies are beginning to come to grips with air pollution. Information about air pollution control agencies in your geographical area can be found in the "Directory of Governmental Air Pollution Agencies," which can be obtained from:

Air Pollution Control Association
4400 Fifth Avenue
Pittsburgh, Pennsylvania 15213
(412) 621-1100

Gradually pollution controls are being applied. As bad as air pollution currently is, it would be much worse if there were no controls. In the automobile industry, for instance, controls are becoming more stringent. This is an important step since the automobile generates 61% of the total air pollution in the United States.

Air pollution control districts are setting up acceptable standards for pollution concentrations, as well as establishing alert procedures to implement emergency control plans when pollution levels are unacceptable. In California, the Highway Patrol has begun roadside spot checks of automobiles for compliance with carbon monoxide and hydrocarbon emission standards. (It is interesting to note that in the initial phases of this program, one out of every five cars checked was found in violation.)

In this unit, you have been exposed to various types of modelling techniques applied to air pollution. For the most part, you may think that these models are too simple to be of value. However, techniques such as those used in this unit can produce incredibly complex models which have proven themselves very useful. This modelling technique has powerful implications that extend far past the problem of air pollution.

The following ideas are fundamental to any modelling task:

(a) Begin with the simplest model possible.

(b) Look at the consequences of the model and compare to reality.

(c) Change your assumptions and refine the model.

(d) Loop back to (b).

Remember that each model relies on a set of assumptions as well as actual statistical data. Generally, it is these assumptions, rather than the numerical data, that make the model inaccurate.

EXERCISE 24 – Pollution in Your Home Town

Locate and contact the air pollution control agencies that are operating in your area. Is there an air pollution problem? If so, what type of pollutants pose the greatest threat? Who are the worst polluters?

EXERCISE 25 – Pollution Control Programs

What programs are under way to control air pollution in your area. What are the permissible pollutant concentrations? What are the alert levels? What are the economic implications of the control measures?

APPENDIX A – USEFUL CONVERSION FACTORS

1 cubic meter = 1000 liters
1 cubic foot = 28.32 liters

1 square kilometer = 247 acres
1 square mile = 640 acres

1 mile = 1.609 kilometers
1 meter = 3.28 feet

1 ton = 2000 pounds
1 pound = 454 grams

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